The Future of Horticulture

FSA

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Effect of Pre- and Post-harvest Treatments on Quality and Storability of Washington Navel Orange Fruits during Cold Storage

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DOI: https://doi.org/10.37229/fsa.fjh.2024.06.15

CrossMark

Future Science Association

Available online free at
www.futurejournals.org

Print ISSN: 2692-5826

Online ISSN: 2692-5834

Received: 10 May 2024
Accepted: 2 June 2024
Published: 15 June 2024

Abstract: Washington Navel orange (*Citrus sinensis*, L. Osbeck) is the most popular among citrus species. Producers and traders face losses of about 20–40% after harvest due to factors such as mechanical damage, microbial spoilage, and improper handling during storage and transportation. Therefore, proper handling and storage becomes crucial to maintain the quality, freshness, and delay spoilage of oranges. This study was conducted during the 2022/2023 and 2023/2024 seasons to evaluate the efficacy of preharvest foliar applications of silicon oxide at (0.50, 1.00 and 1.50) %, and postharvest dipping in jojoba wax at (25, 50 and 75) % on the quality and storability of Washington Navel orange fruits stored at 5 °C with 85-90% relative humidity. Results showed that, prolonged cold storage significantly increased fruit weight loss, decay percentage, and TSS/acid ratio, especially in control fruits, while firmness and vitamin C content gradually declined. Treated fruits showed better quality retention, particularly those treated with silicon oxide at 1.50% and jojoba wax at 75%, which were the most effective in minimizing weight loss and decay and maintaining fruit firmness. Jojoba wax at 50% and 75% significantly preserved vitamin C levels, while the highest TSS content was observed in jojoba wax-treated fruits. Acidity was best maintained with jojoba wax at 75%, followed by silicon oxide at 1.50%, contributing to a more favorable TSS/acid ratio. Total and reducing sugars increased in control fruits but were significantly suppressed by treatments, especially jojoba wax at 75%, whereas, non-reducing sugars showed no consistent trend. Overall, silicon oxide at 1.50% and jojoba wax at 75% were the most effective treatments for preserving the physical and chemical quality of Washington Navel orange fruits under cold storage.

Key words: Silicon oxide, Jojoba wax, Washington navel orange, Fruit quality and Storability.

1. Introduction

The most important fruit grown in Egypt is citrus. The most widely grown citrus fruit is the Navel orange (*Citrus sinensis*, L. Osbeck). Navel orange also is important source of early season income for citrus growers in some commercial citrus areas of the world. In citrus industry, generally, postharvest diseases such as soft rot of fruits, due to fungal infections cause significant economic losses during storage, transport and marketing (**Poppe *et al.*, 2001**). The main method to control postharvest diseases is based on application of synthetic chemical products.

No doubt that the process of fruit handling and storage for local market and export is as important as horizontal and vertical extension of agriculture production. Most fruits have a longer shelf life if they are promptly chilled after harvest. Temperature has a direct effect on the respiration rates of fruits and on the activity of decay caused by microorganisms. Generally, low storage temperatures are used to extend fruit postharvest life (**Manning, 1996**). Furthermore, Postharvest operations are promising approaches for regulating food safety.

Various technologies have recently emerged to preserve fresh produce and extend its shelf life. However, consumers demand chemical-free fresh products with excellent quality and nutritional profiles. In this context, the edible coating of fresh produce seems to be a practical approach to mitigate safety production and quality issues (**Khalid *et al.*, 2022**). Several attempts were conducted to prolong the marketing season of Washington Navel orange fruits. Among these attempts besides cold storage are the uses of jojoba wax as emulsifiable natural product. Jojoba oil/wax, derived from the *Simmondsia chinensis* plant, is another promising edible coating. This oil appears as a clear golden liquid at room temperature with a slightly fatty odor, is very stable, does not become rancid or lose antioxidants even after long storage periods, and spreads well and absorbs well (**Abd-Allah *et al.*, 2012**). According to **El-Emam *et al.* (2019)**, it is colorless, odorless, nonvolatile, and rancidity-free. Jojoba oil has antibiotic activity and has been used in the cosmetic and pharmaceutical industries for years. It is not a triglyceride like other plant oils but a mixture of long-chain esters of fatty acids and fatty alcohols (**Sturtevant *et al.*, 2020**)**.** Jojoba oil also possesses anti-inflammatory, anti-parasitic, and antibacterial properties. Several jojoba seed extracts can be utilized as natural food preservatives to protect against the well-known causes of food spoilage and food-borne illnesses (**Umaiyal *et al.*, 2016**). By preventing water loss, strengthening the outermost layer of skin, and controlling gas permeability and transpiration rate, jojoba oil enhances the quality of citrus and mango fruits (**Abd El-Moniem *et al.*, 2008 and Din *et al.*, 2015**).

As a quantitatively major inorganic constituent of higher plants, silicon (Si) has a multitude of functions in plants, and influences plant development, growth and disease resistance (**Epstein, 1994**). Efficacy of Si on reduction of postharvest diseases has been reported in several fruits, such as sweet cherry (**Qin and Tian, 2005**), jujube (**Tian *et al.*, 2005**), and Hami melon (**Bi *et al.*, 2006**). The induction of defense responses, such as the elicitation of phenylalanine ammonia-lyase (PAL), peroxidase (POD), polyphenoloxidase (PPO), and tissue browning in sweet cherries (**Qin and Tian, 2005**), as well as the PAL, POD, and Si content in Chinese cantaloupe (**Liu *et al.*, 2009**), are the primary focus of studies on the mechanisms that protect fruits from fungal infection by Si. There is, however, little knowledge regarding how Si affects fungal infections. Moreover, a recent study has described a significant reduction in the postharvest deterioration of physico-chemical characteristics on mango after a preharvest potassium silicate treatment (**Mohamed *et al.*, 2017**). Likewise, silicon salts have been used in a number of citrus fruit investigations. **Liu *et al.* (2010)** reported the antifungal effect of sodium silicate on controlling green mold in *C. reticulata*.

There is insufficient information on the specific effect of silicon oxide (SiO_2) on the prevention of fungal infections and maintenance of postharvest quality in stored citrus fruits. The low toxicity of these substances also allows silicon oxide and jojoba wax to be used in agricultural products intended for human consumption. Therefore, this study aims to evaluate the efficacy of silicon oxide pre-harvest foliar applications and jojoba wax postharvest dipping on quality and storability of Washington Navel orange fruits during cold storage.

2. Materials and Methods

This investigation was carried out during the two successive seasons of (2022/2023 and 2023/2024) on 15-years-old Washington Navel orange (*Citrus sinensis* L. *Osbeck*) trees budded on sour orange (*Citrus aurantium,* L.) rootstock, to evaluate the efficacy of silicon oxide pre-harvest foliar applications and jojoba wax postharvest dipping on quality and storability of Washington Navel orange fruits during cold storage. Trees were growing in sandy soil in a private orchard at El-Nubaria district, El-Behira governorate, Egypt. Trees received normal horticultural practices including: drip irrigation, fertilization, pruning, as well as pest and disease control. The trees were planted at (4.0 × 4.5) meters apart.

Twenty-one uniform trees distributed in the orchard were selected for this investigation. This experiment consisted of seven treatments arranged in factorial analysis in a completely randomized design. Three replicates were chosen for each treatment with one tree in each replicate.

The trees were divided into three sections: control "water only", group one and group two. Trees in group one were sprayed one week before harvest (Late November) during 2022/2023 and 2023/2024, respectively) with silicon oxide at (0.50, 1.00 and 1.50) %, (which was purchased from Sigma-Aldrich Co. (USA) and used as received).

Washington Navel orange fruits were picked at ripening stage (Beginning of December) in both experimental seasons. Fruits were cleaned with 0.01% sodium hypochlorite water solution for 2 min and completely air dried at room temperature, sorted, graded and the detective fruits including wounded and other disorders were excluded.

Moreover, the fruits in group two were immersed in; jojoba wax at (25, 50 and 75) %, (which was obtained from MK GORUP FOR DESESRT LAND RECLAMATIO, Alexandria, Egypt). All solutions containing Tween-80 0.05% (v/v). After immersing for 5 min in treatments, fruits were air dried for half hour at room temperature. For physical and chemical determinations during storage time, fruit samples as 30 fruits were taken randomly from each replicate within each treatment. The fruits uniformed in size and color were sampled randomly from each tree were packed in wooden tray and stored under cold condition (5 ˚C with 85-90% RH). Every 20 days during the storage periods, ten fruits from each wooden tray were utilized to calculate weight reduction. Five fruits were also, taken from the wooden tray every 20 days for the determination of physical and chemical fruit properties.

2.1. Physical properties

2.1.1. Fruit weight loss percentage

Was measured by the difference between the initial and final weight of each replication. It was expressed as a percent (%) using the following equation:

$$\text{Weight loss \%} = \frac{\text{(Initial weight of fruits – Weight of fruits at inspection date)}}{\text{Initial weight of fruits}} \times 100$$

2.1.2. Fruit decay percentage

The percentage of decayed fruits included all of the spoiled fruits resulted from rots, fungus, bacterial and pathogens were assessed and the defects were calculated as follows:

$$\text{Decay \%} = \frac{\text{No. of decayed fruits}}{\text{No. of fruit at the beginning of storage}} \times 100$$

2.1.3. Fruit firmness (Ib/inch^2)

Fruit firmness was measured in peel and pulp using pressure tester (Digital force- Gouge Model FGV-0.5A to FGV-100A. shimpo instruments) and expressed as (Ib/inch^2).

2.2. Chemical properties

2.2.1. Total soluble solids percentage

A hand refractometer was used to determine the total soluble solids percentage in fruit juice.

2.2.2. Vitamin C (mg/100ml Juice)

Vitamin C content was determined in fruit juice using 2,6- dichlorophenol-indo-phenol blue dye as mg ascorbic acid per 100 ml Juice. (**A.O.A.C., 1980**).

2.2.3. Acidity percentage:

Fruit juice acidity was determined according to (**A.O.A.C., 1980**) by titration with 0.1 N sodium hydroxide using phenolphthalein as an indicator and expressed as citric acid percentage.

2.2.4. TSS/acid ratio

The ratio was recorded by dividing TSS value by total acidity value.

2.2.5. Sugars determination

For sugars determination, the flesh of each fruit sample was cut into small pieces by a clean knife and mixed well. Five grams of the cut flesh were taken and extracted by distilled water according to (**A.O.A.C., 1980**). Using sulfuric acid and phenol, the total sugars were measured colorimetrically in accordance with (**Malik and Singh, 1980**). The Nelson arsenate-molybdate colorimetric approach was used to identify the reducing sugars (**Dubois *et al.*, 1956**). The difference between total and reducing sugars was used to determine the non-reducing sugars.

2.3. Statistical analysis

Data of the present study were subjected to the analysis of variance test (ANOVA) as completely randomized design (CRD). Where the first factor was for seven treatments mentioned before, the second factor was for storage period. The least significant differences (LSD) at the 5% level of probability were calculated using a computer program Costat according to **Sendecor and Cochran (1980)**.

4. Results

4.1. Fruit weight loss

Data of studying the effect of silicon oxide preharvest application and jojoba wax postharvest dipping on weight loss percentage of Washington Navel orange fruits under cold condition (5 ˚C with 85-90% RH) in 2022/2023 and 2023/2024 seasons are illustrated in Table (1). Results indicated that, in both seasons, the fruit weight loss significantly increased with increasing storage period, as it reached its highest values at the end of the storage periods in control and other treatments, and control recorded a significantly higher fruit weight loss than other treatments.

Statistical analysis, also showed that, silicon oxide and jojoba wax treatments significantly decreased fruit weight loss compared with untreated fruits (Control) in both seasons of study. Moreover, the treatments of silicon oxide at 1.50% and jojoba wax at 75% were more effective on decreasing fruit weight loss, and the differences are big enough to be significant compared with other treatments.

As for the interaction between mentioned treatments and storage period, data showed that, during storage periods, the silicon oxide at 1.50% treatment showed significant superiority in decreasing fruit weight loss, followed by jojoba wax at 75% compared to other treatments, and this was in both seasons, respectively. It should be noted that all treatments had an effect in maintaining the weight loss of the fruits, as the highest weight loss values (7.63 and 7.84) % was obtained for the untreated fruits at the end of the storage period (60 days) in in 2022/2023 and 2023/2024, respectively.

Table (1). Effect of silicon oxide preharvest foliar application and jojoba wax postharvest dipping on weight loss percentage of Washington Navel orange fruits under cold condition (5 ˚C with 85-90% R.H.) in 2022/2023 and 2023/2024 seasons

Treatments	Storage Periods (Days)					
	0	15	30	45	60	Means
	Season 2022/2023					
Control	0.00	2.34	5.24	6.55	7.63	**4.35**
Silicon Oxide 0.50%	0.00	1.55	2.21	3.40	4.44	**2.32**
Silicon Oxide1.00%	0.00	1.45	2.06	3.05	4.09	**2.13**
Silicon Oxide 1.50%	0.00	1.31	1.69	2.46	3.07	**1.70**
Jojoba Wax 25%	0.00	1.90	3.93	5.05	5.99	**3.38**
Jojoba Wax 50%	0.00	1.65	3.13	4.66	5.23	**2.93**
Jojoba Wax 75%	0.00	1.39	1.72	2.84	3.27	**1.84**
Means	**0.00**	**1.65**	**2.85**	**4.00**	**4.82**	
LSD at $_{0.05}$	**(T): 0.06 (D): 0.07 (T×D): 0.16**					
	Season 2023/2024					
Control	0.00	2.66	5.46	6.17	7.84	**4.42**
Silicon Oxide 0.50%	0.00	1.64	2.42	3.57	4.64	**2.45**
Silicon Oxide1.00%	0.00	1.51	2.13	3.21	4.20	**2.21**
Silicon Oxide 1.50%	0.00	1.39	1.72	2.51	3.18	**1.76**
Jojoba Wax 25%	0.00	1.98	4.24	5.29	6.09	**3.52**
Jojoba Wax 50%	0.00	1.71	3.30	4.78	5.35	**3.03**
Jojoba Wax 75%	0.00	1.46	1.83	3.03	3.39	**1.94**
Means	**0.00**	**1.76**	**3.01**	**4.08**	**4.96**	
LSD at $_{0.05}$	**(T): 0.07 (D): 0.06 (T×D): 0.16**					
	T: Treatments D: Storage Periods (Days) T×D: Interaction					

4.2. Fruit decay

The effect of silicon oxide preharvest application and jojoba wax postharvest dipping on fruit decay percentage of Washington Navel orange fruits under cold condition (5 ˚C with 85-90% RH) in 2022/2023 and 2023/2024 is illustrated in Table (2). Data showed that, the percentage of fruit decay significantly increased with increasing storage period, as it reached its highest values at the end of the storage period in control. Additionally, data also indicated that, all treatments significantly decreased fruit decay percentage compared with control in both seasons of study. Furthermore, silicon oxide at 1.50% followed by jojoba wax at 75% was more effective on decreasing fruit decay percentage, and the differences are big enough to be significant compared with other treatments.

Concerning the effect of the interaction between the treatments and storage period, the results revealed that, the minimum values of the fruit decay percentage were obtained at zero time of cold storage and during cold storage in fruits treated with silicon oxide at 1.50%, followed by jojoba wax at 75%, while the maximum values of the fruit decay percentage were recorded at 60 days, especially in untreated fruits (15.90 and 15.85) % in 2022/2023 and 2023/2024, respectively.

4.3. Fruit firmness

Data concerning the effect of silicon oxide preharvest application and jojoba wax postharvest dipping on fruit firmness of Washington Navel orange fruits under cold condition (5 ˚C with 85-90% RH) in 2022/2023 and 2023/2024 seasons are reported in Table (3). Statistical analysis showed that, in both seasons of study, fruit firmness significantly decreased gradually with the progress of cold storage.

Furthermore, silicon oxide preharvest application and jojoba wax postharvest dipping caused a significant increase in fruit firmness compared with control. Moreover, highest values on fruit firmness were recorded with jojoba wax at 75% (14.74 and 15.41) Ib/inch^2 followed by silicon oxide at 1.50% (14.44 and 14.94) Ib/inch^2 in 2022/2023 and 2023/2024 seasons, respectively.

Table (2). Effect of silicon oxide preharvest foliar application and jojoba wax postharvest dipping on fruit decay percentage of Washington Navel orange fruits under cold condition (5 °C with 85-90% R.H.) in 2022/2023 and 2023/2024 seasons

Treatments	Storage Periods (Days)					
	0	15	30	45	60	Means
	Season 2022/2023					
Control	0.00	2.90	6.94	11.94	15.90	**7.53**
Silicon Oxide 0.50%	0.00	0.40	1.50	2.63	3.55	**1.62**
Silicon Oxide1.00%	0.00	0.13	1.08	2.14	3.02	**1.27**
Silicon Oxide 1.50%	0.00	0.00	0.75	1.64	2.06	**0.89**
Jojoba Wax 25%	0.00	0.54	2.07	3.53	4.80	**2.19**
Jojoba Wax 50%	0.00	0.29	1.20	2.29	3.24	**1.41**
Jojoba Wax 75%	0.00	0.00	0.86	1.72	2.22	**0.96**
Means	**0.00**	**0.61**	**2.06**	**3.70**	**4.97**	
LSD at $_{0.05}$	**(T): 0.20 (D): 0.17 (T×D): 0.44**					
	Season 2023/2024					
Control	0.00	2.87	6.77	12.10	15.85	**7.52**
Silicon Oxide 0.50%	0.00	0.28	1.67	2.74	3.68	**1.67**
Silicon Oxide1.00%	0.00	0.17	1.16	2.22	3.18	**1.35**
Silicon Oxide 1.50%	0.00	0.13	0.85	1.76	2.20	**0.99**
Jojoba Wax 25%	0.00	0.47	1.88	3.24	4.34	**1.99**
Jojoba Wax 50%	0.00	0.22	1.16	2.18	3.25	**1.36**
Jojoba Wax 75%	0.00	0.19	0.90	1.84	2.31	**1.05**
Means	**0.00**	**0.62**	**3.06**	**3.72**	**4.97**	
LSD at $_{0.05}$	**(T): 0.11 (D): 0.09 (T×D): 0.24**					
	T: Treatments D: Storage Periods (Days) T×D: Interaction					

Table (3). Effect of silicon oxide preharvest foliar application and jojoba wax postharvest dipping on fruit firmness (Ib/inch^2) of Washington Navel orange fruits under cold condition (5 °C with 85-90% R.H.) in 2022/2023 and 2023/2024 seasons

Treatments	Storage Periods (Days)					
	0	15	30	45	60	Means
	Season 2022/2023					
Control	19.62	16.34	13.70	9.84	7.30	**13.36**
Silicon Oxide 0.50%	20.05	16.76	13.93	9.93	7.65	**13.66**
Silicon Oxide1.00%	19.89	16.94	14.32	9.97	7.90	**13.80**
Silicon Oxide 1.50%	19.58	17.76	14.98	10.87	9.02	**14.44**
Jojoba Wax 25%	19.96	16.90	14.20	10.06	7.85	**13.79**
Jojoba Wax 50%	20.10	17.23	14.71	10.25	8.07	**14.07**
Jojoba Wax 75%	19.97	18.02	15.15	11.25	9.34	**14.74**
Means	**19.88**	**17.14**	**14.43**	**10.31**	**8.16**	
LSD at $_{0.05}$	**(T): 0.20 (D): 0.17 (T×D): 0.46**					
	Season 2023/2024					
Control	20.34	16.75	14.02	10.34	7.83	**13.86**
Silicon Oxide 0.50%	20.49	16.90	14.20	10.59	7.93	**14.02**
Silicon Oxide1.00%	20.51	17.32	14.91	10.87	8.84	**14.49**
Silicon Oxide 1.50%	20.38	17.84	15.42	11.87	9.20	**14.94**
Jojoba Wax 25%	20.59	17.08	14.55	10.87	8.23	**14.26**
Jojoba Wax 50%	20.55	17.59	15.17	11.22	9.04	**14.71**
Jojoba Wax 75%	20.62	18.32	15.97	12.29	9.87	**15.41**
Means	**20.49**	**17.40**	**14.89**	**11.15**	**8.71**	
LSD at $_{0.05}$	**(T): 0.08 (D): 0.07 (T×D): 0.19**					
	T: Treatments D: Storage Periods (Days) T×D: Interaction					

As for the interaction effect between the tested treatments and storage periods, it is obvious that, the minimum values of the fruit firmness were obtained at after 60 days storage with untreated fruits (7.30 and 7.83) Ib/inch^2 in both seasons in 2022/2023 and 2023/2024, respectively. Whereas, jojoba wax at 75% followed by silicon oxide at 1.50% were more effective on maintaining Washington Navel orange fruits during storage periods, and the differences are big enough to be significant compared with other treatments.

4.4. Vitamin C

The effect of silicon oxide preharvest application and jojoba wax postharvest dipping on vitamin C of Washington Navel orange fruits under cold condition (5 ˚C with 85-90% RH) in 2022/2023 and 2023/2024 seasons are offered in Table (4). Results showed that, fruit vitamin C contents decreased with longer storage times in both seasons. The control group had the smallest values of fruit vitamin C (48.13 and 47.81) mg/100ml Juice in 2022/2023 and 2023/2024, respectively. Whereas, silicon oxide and jojoba wax caused a significant increase in fruit vitamin C contents compared with control in both seasons of study. In two seasons, the treatments with jojoba wax at concentrations of 50% or 75% caused a higher effect in increasing fruit vitamin C contents than those of other treatments and the differences were big enough to be significant.

The interaction between mentioned treatments and storage period were significant, where, Washington Navel orange fruits treated with silicon oxide and jojoba wax were recorded the biggest values of vitamin C as compared with untreated fruits along the storage period. Additionally, during cold storage, the treatment of jojoba wax at 50% followed by jojoba wax at 75% were more effective on preserving fruit vitamin C contents compared with other treatments.

Table (4). Effect of silicon oxide preharvest foliar application and jojoba wax postharvest dipping on vitamin C (mg/100ml Juice) of Washington Navel orange fruits under cold condition (5 ˚C with 85-90% R.H.) in 2022/2023 and 2023/2024 seasons

Treatments	**Storage Periods (Days)**					
	0	**15**	**30**	**45**	**60**	**Means**
	Season 2022/2023					
Control	57.17	50.64	47.05	44.25	41.56	**48.13**
Silicon Oxide 0.50%	58.41	55.83	53.02	48.30	44.05	**51.92**
Silicon Oxide1.00%	58.70	56.81	54.41	52.71	48.83	**54.29**
Silicon Oxide 1.50%	59.70	58.10	54.97	52.97	49.70	**55.09**
Jojoba Wax 25%	60.65	58.07	54.22	50.45	47.98	**54.11**
Jojoba Wax 50%	59.57	58.69	56.38	52.94	50.13	**55.54**
Jojoba Wax 75%	59.61	58.99	56.82	53.34	51.87	**56.13**
Means	**58.99**	**56.73**	**53.84**	**50.71**	**47.73**	
LSD at $_{0.05}$	**(T): 0.63 (D): 0.53 (T×D): 1.40**					
Season 2023/2024						
Control	58.18	49.80	46.52	43.68	40.86	**47.81**
Silicon Oxide 0.50%	57.66	55.65	53.05	49.07	44.56	**52.00**
Silicon Oxide1.00%	58.53	56.24	54.90	50.34	47.67	**53.54**
Silicon Oxide 1.50%	58.22	56.84	55.20	51.89	48.12	**54.05**
Jojoba Wax 25%	59.78	57.05	53.77	49.87	46.78	**53.45**
Jojoba Wax 50%	60.38	57.98	55.88	51.85	49.91	**55.20**
Jojoba Wax 75%	60.30	59.09	56.54	52.89	50.76	**55.92**
Means	**59.01**	**56.09**	**53.69**	**49.94**	**46.95**	
LSD at $_{0.05}$	**(T): 0.29 (D): 0.25 (T×D): 0.65**					
	T: Treatments D: Storage Periods (Days) T×D: Interaction					

4.5. Total soluble solids

The effect of silicon oxide preharvest application and jojoba wax postharvest dipping on TSS percentage of Washington Navel orange fruits under cold condition (5 ˚C with 85-90% RH) in 2022/2023 and 2023/2024 seasons are listed in Table (5). Statistical analysis showed that, with the progress of the storage period, the results noticed a gradual increase in total soluble solids and the differences were statistically significant when compared to the beginning date. Additionally, the treatments of silicon oxide and jojoba wax at all concentrations significantly increased fruit TSS contents as compared with control in both seasons of study. The maximum values of TSS were achieved with jojoba wax at 75% (12.75 and 12.74) %, followed by jojoba wax at 50% (12.48 and 12.44) %, where, the minimum values of TSS were achieved with control treatments (11.53 and 11.56) % in 2022/2023 and 2023/2024 seasons, respectively.

Furthermore, the interaction effect of used treatments and storage periods, data showed that, during storage periods, there was a significant increased fruit TSS contents as compared with control in both seasons of study. The highest values of TSS were achieved with jojoba wax at 75% (13.53 and 13.64) %, while, the lowest values of fruit TSS contents are caused with control treatments (11.80 and 11.84) %, at the end of the storage period (60 days) in 2022/2023 and 2023/2024 seasons, respectively.

Table (5). Effect of silicon oxide preharvest foliar application and jojoba wax postharvest dipping on TSS percentage of Washington Navel orange fruits under cold condition (5 ˚C with 85-90% R.H.) in 2022/2023 and 2023/2024 seasons

Treatments	Storage Periods (Days)					
	0	15	30	45	60	Means
	Season 2022/2023					
Control	11.28	11.39	11.52	11.69	11.80	**11.53**
Silicon Oxide 0.50%	11.58	11.60	11.68	11.87	11.96	**11.74**
Silicon Oxide1.00%	11.59	11.65	11.79	11.98	12.14	**11.83**
Silicon Oxide 1.50%	11.50	11.71	11.87	12.14	12.34	**11.91**
Jojoba Wax 25%	11.55	12.07	12.45	12.65	12.84	**12.31**
Jojoba Wax 50%	11.79	12.32	12.53	12.77	12.99	**12.48**
Jojoba Wax 75%	11.65	12.55	12.83	13.18	13.53	**12.75**
Means	**11.56**	**11.90**	**12.09**	**12.33**	**12.51**	
LSD at $_{0.05}$	**(T): 0.07 (D): 0.06 (T×D): 0.16**					
	Season 2023/2024					
Control	11.36	11.42	11.57	11.62	11.84	**11.56**
Silicon Oxide 0.50%	11.51	11.63	11.72	11.83	11.93	**11.73**
Silicon Oxide1.00%	11.56	11.69	11.77	11.95	12.19	**11.83**
Silicon Oxide 1.50%	11.57	11.75	11.90	12.19	12.39	**11.96**
Jojoba Wax 25%	11.45	12.18	12.49	12.70	12.91	**12.35**
Jojoba Wax 50%	11.51	12.27	12.57	12.79	13.07	**12.44**
Jojoba Wax 75%	11.58	12.41	12.74	13.34	13.64	**12.74**
Means	**11.50**	**11.91**	**12.11**	**12.35**	**12.57**	
LSD at $_{0.05}$	**(T): 0.05 (D): 0.04 (T×D): 0.12**					
	T: Treatments D: Storage Periods (Days) T×D: Interaction					

4.6. Acidity

Results tabulated Table (6) showed the effect of silicon oxide preharvest application and jojoba wax postharvest dipping on acidity percentage of Washington Navel orange fruits under cold condition (5 ˚C with 85-90% RH) in 2022/2023 and 2023/2024 seasons. Statistical analysis cleared that, fruit acidity contents gradually decreased with the progress of the storage period and the differences were statistically significant when compared to the zero date. Moreover, control treatment gave the lowest values of fruit acidity (0.781 and 0.758) %, however, silicon oxide and jojoba wax treatments significantly maintaining fruit acidity contents compared with control. In this respect, the highest values of fruit acidity contents were recorded with jojoba wax at 75% (0.953 and 0.977) %, followed by jojoba wax at 50% (0.921 and 0.912) %, then silicon oxide at 1.50% (0.908 and 0.927) % in 2022/2023 and 2023/2024 seasons, respectively.

Furthermore, the interaction between treatments and cold storage periods, silicon oxide and jojoba wax treatments had a highly significantly on fruit acidity percentage compared with control in two seasons. The two high concentrations of jojoba wax (50 and 75) % and silicon oxide at 1.50% were more effective on preserving fruit acidity contents compared with other treatments in both seasons of this study.

Table (6). Effect of silicon oxide preharvest foliar application and jojoba wax postharvest dipping on acidity percentage of Washington Navel orange fruits under cold condition (5 ˚C with 85-90% R.H.) in 2022/2023 and 2023/2024 seasons

Treatments	Storage Periods (Days)					
	0	15	30	45	60	Means
	Season 2022/2023					
Control	1.266	0.888	0.691	0.562	0.501	**0.781**
Silicon Oxide 0.50%	1.200	0.911	0.792	0.619	0.564	**0.817**
Silicon Oxide1.00%	1.176	0.971	0.890	0.686	0.621	**0.868**
Silicon Oxide 1.50%	1.173	0.995	0.887	0.793	0.693	**0.908**
Jojoba Wax 25%	1.135	1.004	0.878	0.658	0.601	**0.855**
Jojoba Wax 50%	1.195	1.062	0.931	0.723	0.695	**0.921**
Jojoba Wax 75%	1.166	1.077	0.988	0.822	0.714	**0.953**
Means	**1.187**	**0.987**	**0.865**	**0.695**	**0.627**	
LSD at $_{0.05}$	**(T): 0.027 (D): 0.023 (T×D): 0.060**					
Season 2023/2024						
Control	1.178	0.895	0.706	0.517	0.495	**0.758**
Silicon Oxide 0.50%	1.187	0.929	0.805	0.612	0.571	**0.821**
Silicon Oxide1.00%	1.171	0.981	0.906	0.644	0.594	**0.859**
Silicon Oxide 1.50%	1.192	0.999	0.884	0.855	0.706	**0.927**
Jojoba Wax 25%	1.151	1.002	0.856	0.647	0.597	**0.850**
Jojoba Wax 50%	1.155	1.099	0.973	0.712	0.622	**0.912**
Jojoba Wax 75%	1.191	1.102	0.991	0.862	0.738	**0.977**
Means	**1.175**	**1.001**	**0.874**	**0.693**	**0.618**	
LSD at $_{0.05}$	**(T): 0.015 (D): 0.013 (T×D): 0.107**					
	T: Treatments D: Storage Periods (Days) T×D: Interaction					

4.7. TSS/acid ratio

Results of the present investigation, presented in Table (7) showed the effect of silicon oxide preharvest application and jojoba wax postharvest dipping on TSS/acid ratio of Washington Navel orange fruits under cold condition (5 ˚C with 85-90% RH) in 2022/2023 and 2023/2024 seasons. Data showed that fruits TSS/acid ratio content are increased with increasing storage periods, and the differences among all tested storage periods were statistically significant compared with the initial date in the two seasons of study. In addition, fruit TSS/acid ratio content significantly increased with control treatment as compared with silicon oxide and jojoba wax treatments in two seasons of study. Furthermore, the maximum values of TSS/acid ratio (16.57 and 17.14) % were recorded with control treatment, while, the minimum values of TSS/acid ratio (13.67 and 13.35) % were recorded with silicon oxide at 1.50%, then (13.93 and 13.56) % with jojoba wax at 75% in 2022/2023 and 2023/2024 seasons, respectively.

In this respect, the interaction between treatments and cold storage periods, control treatment had a highly significantly on fruit TSS/acid ratio compared with silicon oxide and jojoba wax treatments in both seasons. Additionally, with the progress of the storage period, the high concentrations of jojoba wax at 75% and silicon oxide at 1.50% were more effective on maintaining fruit TSS/acid ratio compared with other treatments in both seasons of this study.

Table (7). Effect of silicon oxide preharvest foliar application and jojoba wax postharvest dipping on TSS/acid ratio of Washington Navel orange fruits under cold condition (5 ˚C with 85-90% R.H.) in 2022/2023 and 2023/2024 seasons

Treatments	Storage Periods (Days)					
	0	15	30	45	60	Means
	Season 2022/2023					
Control	8.92	12.82	16.73	20.84	23.55	**16.57**
Silicon Oxide 0.50%	9.65	12.74	14.88	19.19	21.21	**15.54**
Silicon Oxide1.00%	9.86	12.00	13.25	17.47	19.57	**14.43**
Silicon Oxide 1.50%	9.81	11.76	13.66	15.31	17.80	**13.67**
Jojoba Wax 25%	10.18	12.02	14.18	19.22	21.39	**15.40**
Jojoba Wax 50%	9.88	11.61	13.47	17.68	18.72	**14.27**
Jojoba Wax 75%	9.99	11.68	12.99	16.04	18.94	**13.93**
Means	**9.75**	**12.09**	**14.16**	**17.96**	**20.17**	
LSD at $_{0.05}$	**(T): 0.49 (D): 0.41 (T×D): 1.09**					
	Season 2023/2024					
Control	9.65	12.76	16.46	22.53	24.31	**17.14**
Silicon Oxide 0.50%	9.70	12.52	14.56	19.34	20.90	**15.40**
Silicon Oxide1.00%	9.87	11.91	12.99	18.55	20.52	**14.77**
Silicon Oxide 1.50%	9.71	11.77	13.47	14.26	17.55	**13.35**
Jojoba Wax 25%	9.95	12.15	14.59	19.65	21.65	**15.60**
Jojoba Wax 50%	9.96	11.17	12.93	17.96	21.01	**14.61**
Jojoba Wax 75%	9.73	11.26	12.85	15.48	18.48	**13.56**
Means	**9.79**	**11.94**	**13.98**	**18.25**	**20.63**	
LSD at $_{0.05}$	**(T): 0.52 (D): 0.44 (T×D): 1.16**					
	T: Treatments D: Storage Periods (Days) T×D: Interaction					

4.8. Total sugars

With respect to the effect of various applied treatments on total sugars contents of Washington Navel orange, in both experimental seasons, the data demonstrated in Table (8) declared that total sugars contents significantly increased as the storage period extended till the end of storage period 60 days. Moreover, the statistical analysis showed that, in two seasons, silicon oxide and jojoba wax treatments significantly decreased fruit total sugars as compared with control. Additionally, jojoba wax at 75% achieved the lowest values (7.51 and 7.51) %, while, control treatment recorded the highest values (7.75 and 7.71) % of total sugars in 2022/2023 and 2023/2024 seasons, respectively.

Concerning the interaction effect of mentioned treatments and storage periods, data noticed that, with the progress of the storage period, there was a significant decreased fruit total sugars content as compared with control in both seasons of study. The highest values of total sugars were achieved with control treatment (7.89 and 7.86) %, at the end of the storage period (60 days), where, jojoba wax at 75% achieved the lowest values (7.63 and 7.64) % at the same time in 2022/2023 and 2023/2024 seasons, respectively.

Table (8). Effect of silicon oxide preharvest foliar application and jojoba wax postharvest dipping on total sugars percentage of Washington Navel orange fruits under cold condition (5 ˚C with 85-90% R.H.) in 2022/2023 and 2023/2024 seasons

Treatments	Storage Periods (Days)					
	0	15	30	45	60	Means
	Season 2022/2023					
Control	7.61	7.69	7.76	7.81	7.89	**7.75**
Silicon Oxide 0.50%	7.57	7.62	7.71	7.78	7.83	**7.70**
Silicon Oxide1.00%	7.53	7.58	7.64	7.72	7.79	**7.65**
Silicon Oxide 1.50%	7.50	7.57	7.60	7.67	7.71	**7.61**
Jojoba Wax 25%	7.49	7.53	7.61	7.69	7.77	**7.62**
Jojoba Wax 50%	7.45	7.49	7.55	7.64	7.71	**7.57**
Jojoba Wax 75%	7.42	7.44	7.49	7.57	7.63	**7.51**
Means	**7.50**	**7.56**	**7.62**	**7.70**	**7.76**	
LSD at 0.05	**(T): 0.02 (D): 0.02 (T×D): 0.14**					
	Season 2023/2024					
Control	7.56	7.65	7.72	7.79	7.86	**7.71**
Silicon Oxide 0.50%	7.56	7.61	7.67	7.73	7.81	**7.68**
Silicon Oxide1.00%	7.54	7.59	7.63	7.70	7.78	**7.65**
Silicon Oxide 1.50%	7.52	7.56	7.59	7.68	7.75	**7.62**
Jojoba Wax 25%	7.51	7.54	7.61	7.67	7.75	**7.62**
Jojoba Wax 50%	7.44	7.49	7.55	7.62	7.69	**7.56**
Jojoba Wax 75%	7.42	7.45	7.50	7.56	7.64	**7.51**
Means	**7.51**	**7.56**	**7.61**	**7.70**	**7.75**	
LSD at 0.05	**(T): 0.01 (D): 0.01 (T×D): 0.08**					
	T: Treatments D: Storage Periods (Days) T×D: Interaction					

4.9. Reducing sugars

The response of reducing sugars percentage of Washington Navel orange fruits under cold condition (5 ˚C with 85-90% RH) in 2022/2023 and 2023/2024 seasons were reported in Table (9). The data indicated that there was a significant decrease in fruit reducing sugars content as the storage period prolonged. Additionally, silicon oxide and jojoba wax treatments significantly decreased fruit reducing sugars as compared with control in two season of study. Moreover, the biggest values of fruit reducing sugars (3.73 and 3.76) % are recorded with control treatment, where, the smallest values of fruit reducing sugars (3.47 and 3.55) % are recorded with jojoba wax at 75% treatment in 2022/2023 and 2023/2024 seasons, respectively.

As for the interaction effect of mentioned treatments and storage periods, data showed that, during cold storage, silicon oxide and jojoba wax treatments significantly decreased fruit reducing sugars as compared with control in two season of study. Moreover, the present data reveal that the lowest values of reducing sugars were recorded for Washington Navel orange fruits treated with postharvest treatments of jojoba wax in descending order preharvest treatments of silicon oxide compared with untreated fruits (control) which had the highest significant means of reducing sugars at the end of storage periods (60 days) in both seasons of study.

Table (9). Effect of silicon oxide preharvest foliar application and jojoba wax postharvest dipping on reducing sugars percentage of Washington Navel orange fruits under cold condition (5 ˚C with 85-90% R.H.) in 2022/2023 and 2023/2024 seasons

Treatments	Storage Periods (Days)					
	0	15	30	45	60	Means
	Season 2022/2023					
Control	3.89	3.79	3.72	3.65	3.58	**3.73**
Silicon Oxide 0.50%	3.87	3.75	3.67	3.60	3.51	**3.68**
Silicon Oxide1.00%	3.90	3.71	3.61	3.55	3.46	**3.65**
Silicon Oxide 1.50%	3.88	3.66	3.57	3.51	3.39	**3.60**
Jojoba Wax 25%	3.88	3.60	3.55	3.49	3.43	**3.59**
Jojoba Wax 50%	3.91	3.52	3.47	3.38	3.29	**3.51**
Jojoba Wax 75%	3.92	3.45	3.41	3.34	3.23	**3.47**
Means	**3.89**	**3.64**	**3.57**	**3.50**	**3.42**	
LSD at 0.05	**(T): 0.1 (D): 0.01 (T×D): 0.06**					
	Season 2023/2024					
Control	3.94	3.82	3.75	3.67	3.61	**3.76**
Silicon Oxide 0.50%	3.94	3.77	3.70	3.62	3.55	**3.72**
Silicon Oxide1.00%	3.92	3.73	3.63	3.57	3.50	**3.67**
Silicon Oxide 1.50%	3.93	3.67	3.59	3.53	3.41	**3.62**
Jojoba Wax 25%	3.95	3.68	3.61	3.56	3.50	**3.66**
Jojoba Wax 50%	3.93	3.62	3.57	3.51	3.45	**3.62**
Jojoba Wax 75%	3.95	3.55	3.46	3.43	3.34	**3.55**
Means	**3.94**	**3.69**	**3.62**	**3.56**	**3.48**	
LSD at 0.05	**(T): 0.01 (D): 0.01 (T×D): 0.07**					
	T: Treatments D: Storage Periods (Days) T×D: Interaction					

4.10. Non-reducing sugars

Concerning the effect of silicon oxide preharvest application and jojoba wax postharvest dipping on non-reducing sugars percentage of Washington Navel orange fruits under cold condition (5 ˚C with 85-90% RH) in 2022/2023 and 2023/2024 seasons are illustrated in Table (10). Regarding the effect of storage periods on the changes in fruit non-reducing sugars were decreased with increasing storage period, and the differences among all tested storage period were statistically significant compared with initial date in the two experimental seasons.

Furthermore, results generally showed that, the non-reducing sugars did not show a constant or regular trend in 2022/2023 season. Even that, it showed a non-significant increase compared with control for silicon oxide at 0.50% jojoba wax at (25, 50 and 75) %, while, a non-significant decrease for silicon oxide at (1.00 and 1.50) %. Additionally, in 2023/2024 season, silicon oxide at (1.00 and 1.50) % caused a significant increase in fruit non-reducing sugars compared with other treatments.

As for the interaction effect of used treatments and storage periods, data showed that, with the progress of storage period, silicon oxide and jojoba wax treatments did not show a constant or regular trend of fruit non-reducing sugars in two seasons of study. While, in 2023/2024 season, silicon oxide at (1.00 and 1.50) % treatments are more effective on increasing non-reducing sugars compared with other treatments during storage periods.

Regarding the interaction between applied treatments and storage periods, the findings indicated that silicon oxide and jojoba wax treatments did not exhibit a consistent or regular pattern of fruit non-reducing sugars in two seasons of study. In contrast, silicon oxide treatments at 1.00% and 1.50% are more successful in increasing non-reducing sugars during storage periods in the 2023/2024 season than other treatments.

Table (10). Effect of silicon oxide preharvest foliar application and jojoba wax postharvest dipping on non-reducing sugars percentage of Washington Navel orange fruits under cold condition (5 ˚C with 85-90% R.H.) in 2022/2023 and 2023/2024 seasons

Treatments	Storage Periods (Days)					
	0	15	30	45	60	Means
	Season 2022/2023					
Control	3.71	3.89	4.04	4.16	4.31	**4.02**
Silicon Oxide 0.50%	3.70	3.87	4.04	5.38	4.31	**4.26**
Silicon Oxide1.00%	3.62	3.87	4.04	4.17	4.33	**4.00**
Silicon Oxide 1.50%	3.62	3.91	4.03	4.17	4.32	**4.01**
Jojoba Wax 25%	3.61	3.93	4.06	4.21	4.33	**4.03**
Jojoba Wax 50%	3.54	3.97	4.08	4.31	4.42	**4.06**
Jojoba Wax 75%	3.50	3.98	4.08	4.23	4.40	**4.04**
Means	**3.62**	**3.92**	**4.05**	**4.37**	**4.35**	
LSD at $_{0.05}$	**(T): 0.26 (D): 0.22 (T×D): 0.58**					
	Season 2023/2024					
Control	3.62	3.83	3.97	4.12	4.25	**3.96**
Silicon Oxide 0.50%	3.62	3.84	3.97	4.11	4.26	**3.96**
Silicon Oxide1.00%	3.62	3.86	4.00	4.13	4.28	**3.98**
Silicon Oxide 1.50%	3.59	3.90	4.01	4.15	4.34	**4.00**
Jojoba Wax 25%	3.56	3.87	4.00	4.11	4.26	**3.96**
Jojoba Wax 50%	3.50	3.87	4.01	4.15	4.28	**3.96**
Jojoba Wax 75%	3.48	3.90	4.04	4.13	4.30	**3.97**
Means	**3.57**	**3.86**	**3.99**	**4.13**	**4.28**	
LSD at $_{0.05}$	**(T): 0.02 (D): 0.02 (T×D): 0.14**					
	T: Treatments D: Storage Periods (Days) T×D: Interaction					

5. Discussion

5.1. Fruit physical properties

In this study, both silicon oxide and jojoba wax were effective in maintaining the postharvest quality of Washington Navel orange fruits under cold condition (5 ˚C with 85-90% R.H.) for up to 8 weeks, such as; exhibited lower weight loss, reduced decay and better firmness retention. In agreement with our results are those obtained by **Dawood *et al.* (2023)** and they indicated that, the fruit weight loss and decay percentages gradually increased as the storage period extended. However, jojoba oil treatment exhibited a significant reduction in the weight loss and decay percentages compared to untreated fruits. Additionally, the interaction between these treatments and the storage periods had a positive effect on reducing fruit weight loss and decay (**Nasrin *et al.*, 2020**). Conversely, uncoated fruits showed higher weight loss and decay than coated fruits. The control fruits had the highest weight loss at the end of the storage period. The reduction in weight loss can be attributed to the coating acting as a semi-permeable barrier against oxygen, carbon dioxide, moisture, and solute movement. This barrier effectively reduces respiration rate, water loss, and oxidation reaction rates (**Abdel-Salam, 2016**). Furthermore, **Abd-Allah *et al.* (2012)** worked on Costata persimmon fruits and found that jojoba treatments reduced weight loss percentage during the storage period compared with the control, however, the differences between jojoba treatments and the control were beginning after 7 days of the storage, since 100% jojoba treatment was the superior in reducing weight loss percentage. These results are in harmony with **Abd El-Moniem *et al.* (2008)** on mango, since they found that jojoba treatments reduced weight loss percentage of mango fruits comparing with the control.

In previous study, **Mohamed *et al.* (2017)** reported reduced weight loss in mango after a preharvest potassium silicate application. These authors noted that the higher concentration potassium silicate led to less weight loss. Lastly, it is probable that the concentration of silicon oxide utilized here was insufficient to cover the fruit and, thus, impart the proper physical features. The above-cited study suggested that the formation of a silicon layer to totally cover the fruit stomata was the main cause of reduced fruit respiration. So, it would be interesting to perform further studies at higher silicon oxide concentrations. **Beltrán *et al.* (2021)**, also, illustrated that, silicon oxide treatments showed the lowest frequency of damaged fruit after 9 storage weeks of 'Valencia Late' oranges with significant differences with the positive control. Consequently, silicon oxide might be regarded as a novel citrus postharvest disease prevention technique. Furthermore, **Youssef *et al.* (2012)** observed minor fruit decay in orange fruit after applying a preharvest sodium silicate treatment, and potassium silicate postharvest applications showed preventive and curative antifungal activity against green mold and blue mold (**Moscoso-Ramírez and Palou, 2014**). In addition, **Bi *et al.* (2006)** reported lower decay incidence and less decay severity in Hami melons (*Cucumis melo* L. var. *inodorus* Jacq.) after several postharvest sodium silicate treatments. The authors explained their findings by stating that the applied sodium silicate was highly soluble after testing it on Hami melons. Perhaps our different silicon oxide solubility could hinder a layer from being formed on fruit. Weight loss reduction is related to greater water vapor resistance because of the hydrophobic characteristics of the film formed by the applied compounds (**Sánchez-González *et al.*, 2011**). Because of unforeseen circumstances like weather, the layer that would have covered the fruit before storage may have been removed when we applied silicon oxide in our preharvest procedures. The silicon oxide effect on reducing *Penicillium* infections has been related to cell wall strengthening (**Epstein, 1999**), which could increase their resistance to senescence. However, our work is the first weight loss study to be carried out after a preharvest silicon oxide application, and the results showed no effect. Moreover, during shelf storage (30 d at 5 ˚C plus 3 d at 20 ˚C and 30 d at 5 ˚C plus 6 d at 20 ˚C), preharvest foliar sprayed Si–Ca mandarin fruit exhibited a significant lower fruit decay by 13%, as compared to the control (**Ziogas *et al.*, 2022**). However, when Si is applied topically, it will polymerize on the leaf surface to create a barrier. This may change the pH and the osmotic potential of the phyllosphere, which could explain the reductions in the development of some foliar diseases (**Tubaña *et al.*, 2015**).

Skin firmness is also an important attribute for the determination of citrus fruit quality and is tightly related to their ability to travel long distances. Si–Ca treated mandarin fruit exhibited a significant increase in fruit firmness values by 14.2% at harvest date, by 19.3% after one-month cold storage, by 16.28% on the third day (30 d at 5 ˚C plus 3 d at 20 ˚C) of shelf storage and by 10.95% on the sixth day of shelf storage (30 d at 5 ˚C plus 6 d at 20 ˚C), as compared to their respective control fruits (**Ziogas *et al.*, 2022**). In other hand, the firmness of the fruits decreased linearly as the storage period increased, while, jojoba oil treatment significantly increased the firmness of the fruits compared to the untreated fruits. Uncoated fruits showed less firmness than coated fruits (**Dawood *et al.*, 2023**). Similar findings were observed in studies on other fruits, such as Persimmon, where treatments with jojoba, improved fruit firmness during storage (**Abd-Allah *et al*., 2012, Khaliq *et al*., 2016** and **Hasan *et al.*, 2020**). Additionally, **Abd-Allah *et al.* (2012)** reported that, the flesh firmness of Costata persimmon fruits was gradually decreased with control treatment beginning at the day 7, while jojoba treatments saved flesh firmness for a long period at the storage compared with the control especially when the fruits treated with the higher three concentrations of jojoba, which positively affected shelf life/day. Based on these parameters; weight loss and firmness of persimmon fruits coated with jojoba oil seemed to have in general long life span in cold storage compared with the control. Furthermore, **Abd El-Moniem *et al.* (2025)** reported that jojoba oil insignificantly increased Avocado firmness fruits. As for cold storage, periods came sequentially, with zero time being the highest, followed by the first week, through the second week, and until the sixth week, which was the lowest in fruit firmness. In the interaction between treatments and periods, jojoba oil treatment in zero time achieved the highest fruit firmness, followed by jojoba oil after one week of storage. The lowest fruit firmness was observed in the control treatment at the fifth and sixth weeks.

5.2. Fruit chemical properties

Our results indicate that preharvest foliar application of silicon oxide and postharvest treatment of fruits with jojoba wax significantly improves the chemical properties of Washington Navel orange fruits and enhances their storage potential. These results are in agreement with those obtained by **Dawood *et al.* (2023)** they indicated that, generally, there was a gradual increase in the "Kensington Pride" mango fruits TSS percentage with extended storage periods, and the maximum significant value was reached after 35 days at 13±1 ˚C. However, jojoba oil treatment mitigated the increase in TSS percentage compared to untreated fruits. The control treatment exhibited the highest significant values of TSS as uncoated fruits showed faster perishable behavior than coated fruits while the treatments using jojoba oil recorded the lowest significant values. **Abd-Allah *et al.* (2012)**, also, worked on Costata persimmon fruits and reported that SSC and total sugars were gradually increased with the control treatments during the storage period, while jojoba treatments showed stability in SSC during the storage periods which consequently affect the fruit shelf life/day. However, it appears that when the concentration of jojoba decreased, the amount of sugar increased. **Abd El-Moniem *et al.* (2025)** illustrated that, jojoba extract significantly increased the average TSS% of fruit. Regarding storage periods, the TSS% gradually decreased significantly over time, reaching a storage period of six weeks. Concerning the interaction between dipping treatments and cold storage periods, the zero time showed the highest TSS% jojoba then after one week. The lowest TSS% appeared in control after six weeks of cold storage. Moreover, **Ziogas *et al.* (2022)** illustrated that, preharvest foliar Si–Ca spray on Clementine Mandarin significantly increased the fruit TSS content by 19.70% at harvest date, by 35.47% after one month of cold storage (30 d at 5 ˚C), by 40.18% at the third day of shelf storage (30 d at 5 ˚C plus 3 d at 20 ˚C) and by 32.10% at the sixth day of shelf storage (30 d at 5 ˚C plus 6 d at 20 ˚C), with respect to their control fruits. **Vijay *et al*. (2016)** also reported in sweet orange that increased sugar which minimize the acidity in fruit or other hand the reduction of acidity might be due to increase in TSS in fruits. On other hand, **Abd El-Gawad (2015)** noticed that, the increasing in total sugars during storage, may be explained by the increase in the respiration rate. In other words, the activity of enzymes involved in sugar catabolism, increased during storage. Moreover, this increase in total sugars during storage may be due to the waterloos so the sugars concentrated in the same weight sample. In addition, the conversion of complex forms of carbohydrates to simple forms of sugars. The mentioned data were in accordance with those obtained by **Ting and Attaway (1971)**. They discovered that the accumulation of sucrose was mostly responsible for the rise in total sugars that occurred when Hamlin and pineapple oranges and Dancy tangerines ripened. As well as, **El-Ansary (2001)** stored mature mango fruits cvs. "Mabrouka", "Mesk" and "Keitt" at 10˚ and 20 ˚C and 90% RH. He found that the percentage of total sugars rose with the progress of storage periods.

The jojoba oil treatment recorded the highest significant values of total acidity percentage, while uncoated fruits showed less total acidity than coated fruits of "Kensington Pride" mango (**Dawood *et al*., 2023**). The decrease in fruit acidity during storage may be attributed to the oxidation of organic acids and their utilization in metabolic processes (**Obenland *et al*., 2011**). The acidity of the fruit is a crucial factor in determining its quality and acceptability, with citric acid being the primary acid found in Washington Navel orange fruit. Respiration is the main cause of the acidity decrease that occurs during storage (**Yaman** and **Bayoindirli, 2002**). **Abd-Allah *et al.* (2012)** also illustrated that, fruit acidity percentage of Costata persimmon was gradually decreased according to the storage period, this was true among all treatments including that of the control. On the other hand, the control treatment showed a high reduction values than jojoba treatments during the storage period. On the other side, a constant trend was detected among jojoba treatments. Additionally, **Abd El-Moniem *et al.* (2025)** noticed that jojoba oil significantly increased fruit titratable acidity. Also, TA decreased significantly over time in terms of storage period. jojoba oil gave the highest TA after one week of cold storage. After six weeks of cold storage for the control treatment, the least amount of TA was seen. **Ziogas *et al.* (2022)** reported that, preharvest foliar Si–Ca application on Clementine Mandarin significantly increased fruit TA by 40.74% at harvest date, by 81.65% after one-month cold storage (30 d at 5 ˚C), by 75% at the third day of shelf storage (30 d at 5 ˚C plus 3 d at 20 ˚C) and by 76.34% at the sixth day of shelf storage (30 d at 5 ˚C plus 6 d at 20 ˚C), with respect to their control fruits. Moreover, the ratio of TSS/TA is used in order to determine the taste of citrus fruits, and mandarin fruits as an indicator of the fruit's maturity stage. In comparison to their control fruits, **Ziogas *et al.* (2022)** found that Si–Ca treated Clementine Mandarin fruit had a significantly lower ratio of TSS/TA by 14.6% at harvest, 25.40% on the third day of shelf storage (30 days at 5 ˚C plus 3 days at 20 ˚C), 19.66% on the third day of shelf storage (30 days at 5 ˚C plus 3 days at 20 ˚C), and 24.81% on the sixth day of shelf storage (30 days at 5 ˚C plus 6 d at 20 ˚C). **Mounika *et al.* (2021)**, also illustrated that, silicon helped in synthesis of more sugars in fruit and thus helped in increasing TSS, an increase in total soluble solids lead to decrease in acidity content, also, the increase in fruit quality may be due to foliar application of silicon in required quantity at correct time intervals to the plant. Furthermore, **Rapisarda *et al.* (2001)** studied orange fruit from two blood varieties and discovered that the two cultivars had a higher maturity index (TSS/Acid) as a result of the increase in total soluble solids for Tarco and the concurrent decrease in total acidity during storage in both varieties.

The ascorbic acid values decreased significantly during the storage period for jojoba oil treatment, reaching their lowest values after 35 days as reported by **Dawood *et al.* (2023)**, however, jojoba oil treatment were effective in reducing the loss of ascorbic acid in "Kensington Pride" mango fruits during cold storage at 10±1˚C. These results align with the study carried out by **El-Baz *et al.* (2021)**, who also observed a reduction in ascorbic acid levels during cold storage. According to **Abdel-Salam (2016)** and **Atrash *et al.* (2018)**, uncoated fruits lost ascorbic acid more quickly than coated fruits, indicating that the coated fruits' retention of ascorbic acid may be due to a decrease in respiration rate and oxidation. The loss of ascorbic acid during storage can generally be attributed to the rapid conversion of L-ascorbic acid into dehydroascorbic acid in the presence of L-ascorbic acid oxidase, as explained by **Hussein *et al*. (2015)**. Moreover, **Abd-Allah *et al.* (2012)** reported that, generally, fruit ascorbic acid content of Costata persimmon was reduced among the storage period with all treatments. However, ascorbic acid was affected by jojoba treatments. In this respect, the lower concentrations were more effective than the highest one. The untreated fruits showed the lower significant values. In addition, **Abd El-Moniem *et al.* (2025)** found that, the lowest vitamin C content was seen in the control treatment, while the highest content was obtained by jojoba oil. Fruit vitamin C content was significantly observed to be high at zero time, and then decreased thoroughly in the sixth week, which was the lowest. The interaction between jojoba oil and cold storage periods illustrated the superiority of all jojoba oil at zero time in vitamin C content, followed by jojoba after one week of storage, respectively. Control group had the lowest values of vitamin C. In addition, **Ziogas *et al.* (2022)** found that, the preharvest foliar spray of Si–Ca significantly affected the AA content of mandarin fruit at the harvest date. After one-month cold storage (30 d at 5 ˚C) of Si–Ca treated fruit, a significant change of ascorbic acid (AA) content by 69.63% was observed over control ones. During shelf storage, at day 3 (30 d at 5 ˚C plus 3 d at 20 ˚C), Si–Ca treated fruit exhibited 55.76% higher AA content than control fruit, whereas, at day 6 (30 d at 5 ˚C plus 6 d at 20 ˚C), a significant increase of 51.76% AA content was observed in Si–Ca treated fruit.

6. Conclusion

The results of this study clearly demonstrated that silicon oxide at 1.50% and jojoba wax at 75% were the most effective treatments in preserving the postharvest quality of Washington Navel orange fruits during cold storage. These treatments significantly reduced fruit weight loss and decay percentage, maintained higher firmness and vitamin C content, and improved total soluble solids compared to the untreated control. They also helped preserve fruit acidity and control the increase in TSS/acid ratio, which was highest in the control fruits. Moreover, both treatments contributed to lowering total and reducing sugars during storage, indicating a delay in ripening and metabolic activity. While non-reducing sugars showed inconsistent trends, silicon oxide at 1.00% and 1.50% showed better performance in increasing their levels. Overall, preharvest application of silicon oxide at 1.50% and postharvest dipping in jojoba wax at 75% proved to be safe, natural, and effective methods to enhance storability and maintain the physicochemical quality of orange fruits, and are therefore recommended for commercial use.

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تأثير معاملات ما قبل وما بعد الحصاد على الجودة والقدرة التخزينية لثمار البرتقال أبوسرة أثناء التخزين المبرد

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يُعد البرتقال أبو سرة الأكثر شيوعًا بين أنواع الحمضيات. يواجه المنتجون والتجار خسائر تتراوح بين (٢٠-٤٠)٪ بعد الحصاد بسبب عوامل مثل التلف الميكانيكي والتلف الميكروبي وسوء التداول أثناء التخزين والنقل. لذلك، يُعد التداول والتخزين الأمثل أمرًا بالغ الأهمية للحفاظ على جودة ثمار البرتقال وتأخير تلفها. أُجريت هذه الدراسة خلال موسمي (٢٠٢٢/٢٠٢٣ - ٢٠٢٣/٢٠٢٤) لتقييم فعالية الرش الورقي قبل الحصاد بأكسيد السيليكون بتركيزات (٠,٥٠، ١,٠٠، ١,٥٠)٪، والغمر بعد الحصاد في شمع الجوجوبا بتركيزات (٢٥، ٥٠، ٧٥)٪ على جودة ثمار البرتقال أبو سرة وقابليتها للتخزين، والمخزنة عند درجة حرارة ٥ درجة مئوية ورطوبة نسبية تتراوح بين (٨٥-٩٠)٪. أظهرت النتائج أن التخزين المبرد لفترات طويلة أدى إلى زيادة كبيرة في فقدان وزن الثمار ونسبة التلف ونسبة المواد الصلبة الذائبة الكلية/الحموضة، وخاصة في ثمار الكنترول (الغير معاملة)، بينما أنخفضت الصلابة ومحتوى فيتامين (ج) تدريجيًا. في حين أظهرت الثمار المعالجة إحتفاظًا أفضل بالجودة، وخاصة تلك المعالجة بأكسيد السيليكون بنسبة ١,٥٠٪ وشمع الجوجوبا بنسبة ٧٥٪، والتي كانت الأكثر فعالية في تقليل فقدان الوزن والتلف والحفاظ على صلابة الثمار. أسهم شمع الجوجوبا بنسبة ٥٠٪ ، ٧٥٪ في الحفاظ بشكل ملحوظ على مستويات فيتامين (ج)، كما لوحظ أعلى محتوى من المواد الصلبة الذائبة الكلية في الثمار المعالجة بشمع الجوجوبا. تم الحفاظ على الحموضة بشكل أفضل مع شمع الجوجوبا بنسبة ٧٥٪، يليه أكسيد السيليكون بنسبة ١,٥٠٪، مما ساهم في تحسين نسبة المواد الصلبة الذائبة الكلية/ الحموضة. زادت السكريات الكلية والمختزلة في الثمار الغير معاملة ولكن تم السيطرة عليها إلى حدَ كبير من خلال المعاملات المستخدمة، وخاصة شمع الجوجوبا بنسبة ٧٥٪، في حين لم تظهر السكريات غير المختزلة أي إتجاه ثابت. بشكل عام، تشير نتائج هذه الدراسة إلى أن رش أشجار البرتقال أبو سرة قبل الجمع بأسبوع بأكسيد السيليكون بتركيز ١,٥٠٪، إلى جانب غمر الثمار بعد الجمع في محلول شمع الجوجوبا بتركيز ٧٥٪، يُعد أكثر المعاملات فعالية في الحفاظ على الصفات الفيزيائية والكيميائية لثمار البرتقال أبو سرة أثناء التخزين المبرد.